Non-LTE Analysis of Lyman-Line Observations of a Filament with SUMER

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Abstract. We present non-LTE diagnostics of the filament observed by SOHO/SUMER on May 27, 2005 in the whole Lyman series. The filament was situated close to the disk center. The Lα observations were carried out with normal voltage of detector A. The slit was placed at the central part of the detector – outside the Lα attenuator. Therefore, the observed profiles of this line could be calibrated reliably.

1. Introduction

In previous works (Schwartz et al. 2006a,b) we made the non-LTE modeling of the profiles of Lβ and higher hydrogen Lyman lines observed in EUV filaments by SoHO/SUMER on October 15, 1999 and May 5, 2000. For the latter EUV filament we had also observations of the Hα profiles from THEMIS/MSDP. In Schwartz et al. (2006a) it was found that estimates the of temperature in the filament interior need not be reliable if there are temperatures lower than $10\,000\,\mathrm{K}$ in the filament interior and rather hot PCTRs (prominence-corona transition regions) with temperatures above $20\,000\,\mathrm{K}$ at the same time. These problems occur especially for the Hα filaments. This problem can be solved by constraining the models with the profile of the Hα line that is not sensitive to the high temperature plasma of PCTRs (Schwartz et al. 2006b). Therefore its shape represent well the temperature structure of the cool filament interior. However, the problem is to find suitable Hα observations with the same position of the slit and made at the same time, as the SoHO/SUMER observations. The optically thick cores of the Lyman lines are formed in the top PCTRs while the optically thick parts of the wings are formed deeper. Wavelength intervals where the profiles of Lβ and higher Lyman lines are optically thick, are small ($\sim \pm 0.2\,\text{Å}$ or even smaller). Outside these interval the filament is transparent. Therefore the wings of these lines do not map the temperature structure of filament much deeper then the top PCTR. The profile of the Lα line could be much more sensitive to the cooler hydrogen plasma deeper in the filament than higher Lyman lines. Its is because of the wide wavelength interval ($\sim \pm 0.3\,-\,1.4\,\text{Å}$ or even larger) of the optically thick part of the profile, possibly spreading far into the wings.

In this work we are modeling profiles of the Lyman lines, Lyman continuum and Hα line observed in the Hα filament using the 1D-slab non-LTE model (Heinzel et al. 1997). As the results of a such diagnostics we obtain the temperatures, the gas pressure, plasma densities, ionization degree etc.
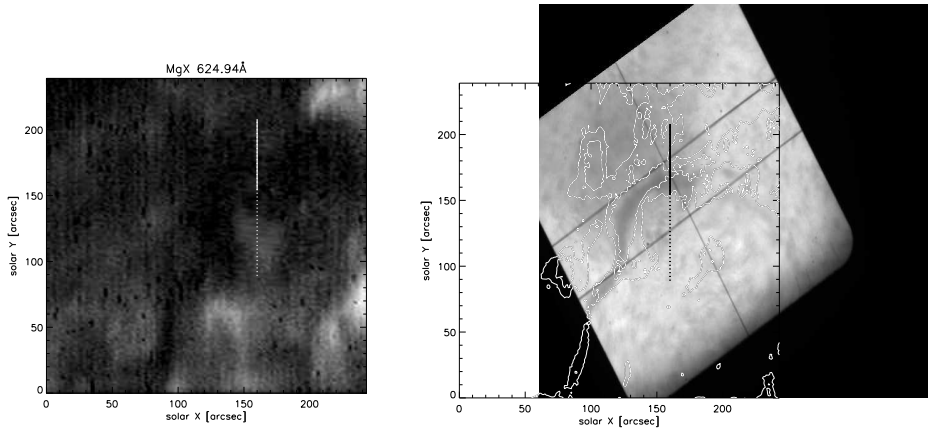
Figure 1. CDS observations of the EUV filament in the Mg X 624.94 Å line are shown in the left panel. In the right panel the slit-jaw of Hα observations of HSFA2 spectrograph are shown. The slit-jaw is co-aligned with the CDS observations of the He I 584 Å line represented by contours. The inclined hair crossed perpendicularly with two other hairs shows the position of the spectrograph slit during the observations of the Hα line. Vertical bar in both panels shows the position of the SUMER slit during the observations of the Lyman line series. Full-line part of the bar marks working part of the SUMER detector A.

2. Observations

A filament close to the solar disk (μ=0.9) was observed on May 27, 2005 (during the 15th MEDOC observing campaign), in EUV spectral lines by the CDS (Coronal Diagnostic Spectrometer) (Harrison et al. 1995) and SUMER (Solar Ultraviolet Measurements of Emitted radiation) (Wilhelm et al. 1995) both on-board of SoHO (Solar and Heliospheric Observatory) and in the Hα line by HSFA2 multicamera spectrograph at Ondřejov observatory. The SUMER observations of the filaments and prominences during this observing campaign are unique because the Lα line was placed on the bare part of the detector A (outside the attenuator) for the first time during any filament/prominence observations and thus it was possible to make a reliable calibration of the observed Lα profiles.

Observations with CDS and SUMER were carried out between 17:14 and 18:07 UT. CDS observed the EUV filament in three coronal EUV lines Mg X 624.94 Å, Ca X 557.77 Å and Mg IX 368.07 Å, two transition-region EUV lines O V 629.73 Å and Ne VI 562.80 Å and one chromospheric line He I 584.33 Å.

Position of the center of CDS rasters is 248″, −67″ (S 5 W 15 in Carrington coordinates) and their dimensions are 244″×240″. CDS observations in the Mg X 624.94 Å line are shown in the left panel of Fig. 1.

The Hα observations were carried out with the HSFA2 multicamera spectrograph of the Ondřejov observatory at 7:14 UT. The slit-jaw co-aligned with the CDS observations is shown in right panel of Fig. 1. The slit positions of HSFA2 and SUMER spectrographs are crossing the filament in different directions and the times of observations of HSFA2 and SoHO differs. However, since
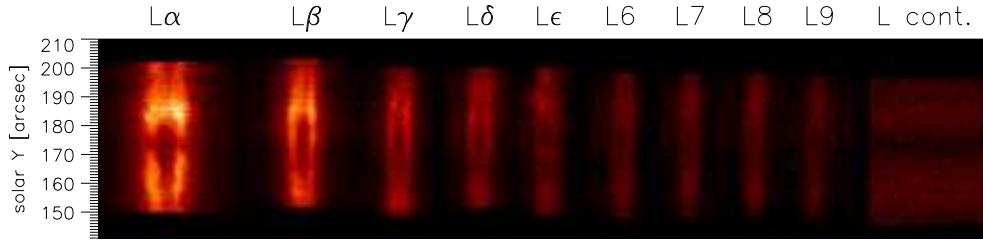
Figure 2.   Spectra of the hydrogen Lyman lines Lα – L9 plus Lyman continuum observed by SUMER with detector A. The slit was positioned across the EUV filament as it is shown in the left panel of Fig. 1. Only 59″ of the spectra were obtained because only a part of the detector was working.

the filament seemed to be rather stable and compact, the HSFA2 observations of Hα could be used as additional data in our non-LTE modeling.

SUMER observed the EUV filament in a wide wavelength range so that the whole hydrogen Lyman line series is present. The spectra of Lyman lines Lα – L9 plus Lyman continuum are shown in Fig. 2. We do not use the lines L10 and L11 because with a 12-level model hydrogen atom our calculated populations of levels 11 and 12 are rather unprecise. Position of the SUMER slit during observation of the Lyman series is shown in Fig. 2. Only a part of the detector A was working therefore we obtained spectra from this part of the slit only (marked by full-line part of vertical bar in both panels of Fig. 1). This part of the slit is crossing almost only the darkest part of the EUV filament – the Hα filament.

3.   Non-LTE Model of the Filament

A filament is approximated by the 1D horizontal isobaric slab (Heinzel et al. 1997) with temperature symmetrically decreasing from PCTRs to the interior. The radiative transfer is solved using MALI method (Heinzel 1995; Paletou 1995) and a 12-level model of the hydrogen atom. We used χ^2 minimization method proposed in Schwartz et al. (2006a) for fitting the observed profiles with synthetic ones. For reconstruction of Lyman line profiles emitted from beneath the filament (background irradiation) we used the method developed in Schwartz et al. (2006a) – the profiles of the background irradiation are identical with profiles from the filament in the optically thin wings. The optically thick cores of Lβ – L9 lines were reconstructed using the quiet-Sun profiles published by Warren et al. (1998). For Lα line the average profiles from the quiet-Sun observations carried out on April 14, 2005 between 13:26 and 14:26 UT were used (Dammasch 2006). During these observations the raster scan in the quiet-Sun area was made and the Lα line was placed at various positions on the bare part of the detector A. There was a problem with the reconstruction of the background-irradiation profiles of the Lα line because the width of the wavelength interval of optically thick central part of its profile is much more sensitive to optical thickness in the line center than it is for higher Lyman lines. Therefore only those optically thick parts of profiles of this line were modeled which transmit no radiation from below the filament.

4. Results and Conclusions

We obtained similar plasma properties as for other two Hα filaments studied in Schmieder et al. (2003) and Schwartz et al. (2006a) – temperatures around $6\,000\,\mathrm{K}$ and $20\,000\,\mathrm{K}$ in the filament interior and PCTRs, respectively. PCTRs both occupy less than $30\,\%$ of the geometrical thickness of the filament, plasma densities are 10^{-14}– $10^{-13}\,\mathrm{g\,cm^{-3}}$, electron densities around $10^{10}\,\mathrm{cm^{-3}}$ and the hydrogen ionization degree is lower than 0.5 in the filament interior. Only the estimated gas pressure $\sim 0.4\,\mathrm{dyn\,cm^{-2}}$ is about 3 times lower than that estimated for two other filaments.

   We compared results of our modeling when fitting profiles of the whole Lyman series plus Lyman continuum without Hα and results obtained with the Hα line but without Lα and found similar plasma properties in both cases. But when fitting only Lyman lines without Lα the temperatures in the filament interior were underestimated. From our analysis of the dependence of the contribution function (computed using Eq. (13) of Heinzel et al. 2005) on the geometrical depth we found that the core of the Lyman lines is formed at the top of PCTR, in contrast with the Hα line profile that is formed almost completely in the cool interior. However, due to large optical thickness of Lα, its near wings are formed in cool parts of the Hα filament and this helps to determine the temperature of the filament interior. Using the Hα line gives a similar result.

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